Signal Priority, Transit Vehicle Data Transfer, Off-Line Verification, ELP, Intersection Collision Avoidance, and Automated Highway System-to-Vehicle Communications) must operate on interference-free frequencies. An allocation of bandwidth must also be made for those DSRC applications that migrate from the 902 to 928 MHz band to the 5.850 to 5.925 GHz band. The analysis of the characteristics of the 5.850 to 5.925 GHz band shows that DSRC operation is possible at these frequencies, sufficient bandwidth is available, few disadvantages exist, and that several significant advantages can be obtained. Therefore, to provide sufficient bandwidth to operate properly and to foster nationwide interoperability, the 5.850 to 5.925 GHz band should be allocated to DSRC services as co-primary with fixed-satellite services, which are already in the band.

8.0 SUMMARY

This paper has addressed three major questions in the debate about the use of beacons to support DSRC in the ITS National Architecture. These questions are summarized as issues of feasibility, capacity, and spectrum management.

On the question of feasibility, the analysis presented in this paper shows the following key points:

- Beacon - tag systems and RF beacon - tag systems in particular, have the underlying capability to support the ITS DSRC role. Our analysis indicates that the maximum data rate required to support ITS operations is less than the data rate supported by beacons.

- RF Beacons are not unduly affected by the normal environmental parameters encountered in highway situations, with the exception that standing water or compacted snow can reduce link operating margins in 5.8 GHz operations.

From the perspective of capacity, a careful consideration of deployment scenarios and functional groupings of ITS DSRC requirements has determined that eight channels will be needed to completely service foreseen requirements.

This is based upon the above eight channels, and a determination of the required channel bandwidth of 6 Mhz.

The channel bandwidth requirement value is based on:

- 600 Kbps data rate capability in the DSRC link.

- The path from Reader to Tag typically employs a simple modulation scheme to minimize the cost of the tag.

- Channel spacing required to prevent interference with adjacent channels and other services.

Reductions in the channel spacing can be achieved by trading spectrum for roadway efficiency or tag cost. More complicated and spectrally efficient modulation schemes will increase tag cost to the user, effectively "raising the entrance fee" into ITS. Restrictions on roadway operations, which would either increase the "read" zone or reduce the number of vehicles that could occupy the zone, could reduce the necessary data rate and hence spectrum. However, these restrictions would limit the overall highway efficiency, in direct opposition to the purpose of ITS.

DSRC applications, including In-Vehicle Signing, International Border Clearance, Electronic Clearance, Safety Inspection, Fleet Management, AEI, and Freight Management, Intersection Collision Avoidance, Emergency Vehicle Signal Preemption, Transit Vehicle Data Transfer, Traffic Network Performance Monitoring, Traffic Information Dissemination, Automated Highway System-to-Vehicle Communications, Electronic Toll Collection (ETC), and Parking Payments are being defined in the ITS architecture as functions to be implemented with RF beacon technology.

Even though installations of the applications were consolidated where possible, full implementation will require more bandwidth than is available in the current LMS 902 to 928 MHz band. Therefore, eight DSRC channels, 6 MHz each, should be allocated to the 5.850 to 5.925 GHz band. Intermodal Freight Management, which is already substantially deployed and involves equipment with different operating requirements, should continue to operate in the 902 to 928 MHz band. Electronic Toll Collection (ETC), Commercial Vehicle Operations (CVO), Traffic Network Performance Monitoring, Parking Payments and related activities which are already deployed in many areas, should continue to operate in the 902 to 928 MHz band until the user and manufacture communities decide to migrate to the 5.850 to 5.925 GHz band. New applications, such as In-Vehicle Signing (Hazard Warning), Emergency Vehicle Signal Preemption, Transit Vehicle Signal Priority, Transit Vehicle Data Transfer, Intersection Collision Avoidance, and Automated Highway System-to-Vehicle Communications should have the 5.850 to 5.925 band made available for use as soon as possible.

The 5.850 to 5.925 GHz band is generally free of interference and would provide a protected place for DSRC applications, many of which are safety-critical or safety-enhancing, to operate.

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[19] Wietfeld, C. and Rokitansky, C-H., "Performance of Vehicle-Roadside Communication Systems Supporting Multiple RTI-Applications," 1994 Vehicle Navigation & Information Systems Conference Proceedings, pp. 133-138.
[20] U.S. Department of Commerce/NTIA, NTIA REPORT 93-294 Federal Government Spectrum Usage in the 902-928, 2400-2500 and 5725-5875 MHz Bands, February 1993
[21] Van Valkenburg M.E., Reference Data for Engineers: Radio, Electronics, Computer and Communications, Eigth Edition, SAMS Prentice Hall Computer Publishing, 1993

Appendix A: DSRC Equipment Characteristics

1.0 Introduction

This appendix summarizes the literature search performed by GTRI and ARINC. The literature search was designed to collect technical, cost and market information on Vehicle-to-Roadside (DSRC) systems operating in the 902-928 MHz and 5.8 GHz frequency bands including:

- Frequency of Operation;
- Modulation Technique;
- Multi-Access Technique;
- Message Transfer Capacity;
- Permissible Operating Environment;
- Physical Deployment / Set-Up Constraints;
- Coverage Zone;
- Cost of Infrastructure (Deployment and NRE);
- Cost of Vehicle Equipment;
- Targeted Market; and
- Market Share.

Section 2.0 presents a summary of the DSRC systems. A basic categorization of the systems is presented. Section 3.0 contains more detailed descriptions of the DSRC systems studied in template form.

2.0 Summary and Categorization of the DSRC Systems

A total of eight operational DSRC system manufacturers were discovered in the literature search. Five of the systems are produced in the United States, one in the United Kingdom, one in Sweden, and one in Germany.

Table 1 lists the DSRC systems investigated in this search, their country of origin and their operating frequencies. All of the currently deployed U.S. systems operate in the 902-928 MHz frequency band. Three U.S. companies currently offer systems that operate in the 5.8 GHz band. However, no data is available on the Amtech and Texas Instruments 5.8 GHz systems. All of the European systems operate in the 5.8 GHz or 2.45 GHz band. Since this effort focuses on the 902-928 MHz and 5.8 GHz bands, the 2.45 GHz systems are not presented here.

Table 1. DSRC Systems

DSRC System	Country	Operating Band
AT/Comm	United States	904.5 MHz, 2.45 GHz or 5.8 GHz
Bosch (MobilPass)	Germany	5.8 GHz
Hughes	United States	902-915 MHz
Amtech: Intellitag	United States	902-928 MHz 5.8 GHz
GEC-Marconi	United Kingdom	5.8 GHz
Nippondenso	Japan-U.S.	2.45 GHz
Mark IV (RoadCheck)	United States	902-928 MHz
Saab-Combitech	Sweden	2.45 GHz 5.8 GHz
Texas Instuments (TIRIS)	United States	902-928 MHz 5.8 GHz
XCI	United States	915 MHz

Most of the DSRC systems looked at in the effort were developed primarily for electronic toll collection (ETC). As such, they were first developed to communicate with vehicles in a single lane. Four of the DSRC system manufacturers also boast multiple access schemes that make the systems capable of communications with several vehicles simultaneously. Table 2 lists the four multiple access DSRC systems and their respective access scheme.

Table 2. Multiple Access Schemes Used by DSRC Systems

DSRC System	Multiple Access Technique
AT/Comm	FM Capture
Hughes	TDMA with Slotted ALOHA
Intellitag	"Flex-Frame" TDMA
Mark IV	TDMA with Slotted ALOHA
Saab-Combitech	TDMA with Slotted ALOHA

The Bosch MobilPass system made no mention of multiple access techniques, but only discussed single-lane/vehicle implementations. The XCI and GEC-Marconi DSRC systems also claim only single-vehicle communications, primarily ETC.

3.0 Templates of DSRC Systems

The following pages contain templates of the information gathered on the DSRC systems operating in the 902-928 MHz and 5.8 GHz frequency bands.

Name of System: **AT/Comm**

Manufacturer: AT/Comm Incorporated
America's Cup Building
30 Doaks Lane
Marblehead, Massachusetts 01945

Contact Person: Dave McLaughlin
Phone: (617) 631 - 1721
Fax: (617) 631 - 9721

System Description: AT/Comm produces DSRC equipment operating on dual frequencies. The roadside-to-vehicle link can operate at 904.5 MHz, 2.45 GHz or 5.86 GHz (licensed). The vehicle-to-roadside link operates in the 40 - 70 MHz band (unlicensed). The flexible architecture allows bi-directional communication, simultaneous multiple applications (up to 18 accounts), and includes location measurement (accuracy < 4 feet).

Detailed Specifications:

Operating Frequency:
Roadside-to-Vehicle: 904.5 MHz, 2.45 GHz or 5.86 GHz (site licensed)
Vehicle-to-Roadside: 40 - 70 MHz (unlicensed).

Modulation Technique:
Roadside-to-Vehicle: AM, balanced Manchester encoded
Vehicle-to-Roadside: FM, balanced Manchester encoded

Necessary Bandwidth:
Roadside-to-Vehicle: 40 kHz (estimated)
Vehicle-to-Roadside: 40 kHz (estimated)

Occupied Bandwidth:
Roadside-to-Vehicle: Not Provided
Vehicle-to-Roadside: Not Provided

Antenna Parameters:
Roadside Unit: Multiple antennas are used depending on application and desired coverage zone. Highly directional antennas are used for single lane ETC applications and lower gain antennas are used for multi-lane and CVO applications.
In-Vehicle Unit: PCB etched antenna (low gain, nearly omni-directional)

Transmitted Power:
Roadside Units: T1 ≤ 600 mW; T2 ≤ 20 mW; Variable depending on installation requirements.
In-Vehicle Unit: ≤ 10 mW

Receiver Sensitivity:
Roadside Unit: -106 dBm
In-Vehicle Unit: -65 dBm

Multi-Access technique: Vehicle-to-roadside multi-access is accomplished using an FM capture technique that differentiates by power received. The claim is that this provides a normal, orderly sequencing of multiple FM messages that reliably and predictably provides multiple access without extra processing or time delays.

Message Transfer Capacity:
Roadside-to-Vehicle: 19,200 Baud ≤32 byte packets (5 byte header, 25 bytes data, 2 byte checksum) - not specified, but assumed to be same as below.
Vehicle-to-Roadside: 19200 Baud, ≤32 byte packets (5 byte header, 25 bytes data, 2 byte checksum)

Permissible Operating Environment: All weather operation. Operating range could be reduced by interference (see Receiver Sensitivity above).

Physical Deployment / Set-Up Constraints: Typically uses a roadside or over-the-road installation of the fixed antennas. In-vehicle unit is installed on the vehicle dash. Works in all weather.

Coverage Zone: This system is designed for longer range operation from roadside-to-vehicle. The actual coverage zone can be small (ETC applications) or larger (CVO applications) depending on the physical set-up.
Roadside-to-Vehicle: Up to 1 mile.
Vehicle-to-Roadside: Up to 1/4 mile

Cost of Infrastructure:
Deployment: Claims an ETC station (single reader) can be installed for little as $500.
NRE:

Cost of In-Vehicle Equipment: $35 - $45, depending on volume

Targeted Market: Electronic Toll Collection (ETC), airport ground transportation management, electronic parking, Commercial Vehicle Operations (CVO) including HAZMAT, and Advanced Traffic Management Systems (ATMS).

Market Share: Currently in use in ETC (Illinois Tollway, Maine Turnpike, UK, Australia), airport ground transportation (Dulles International Airport), and electronic parking.

References

Sales Brochures

Rouke, J., 'Radio That Can Read - And Write," Communications Magazine, December 1992, 24-25.

Name of System: **MobilPass**

Manufacturer: Bosch ANT Telecom
Gerberstrasse 33
71522 Backnang
Germany

Contact Person: W. Detlefsen
Phone: 011-49-5121-49-3903
FAX: 011-49-5121-49-2538
Email: detlefsen@hic334.decnet.bosch.de

System Description: The MobilPass system is an electronic toll collection (ETC) system designed to operate in a multilane, free-flow environment. It features 100% recognition and identification of incorrectly paying or non-paying users. It includes vehicle type/class detection for variable tolls. It uses prepaid electronic cards ("chipcards" or "smartcards") that carry the toll account information. The communications between the vehicle tag and the roadside unit can also be used to transfer traffic information.

Detailed Specifications:

Operating Frequency: 5.8 GHz ±5 MHz

Modulation Technique:
Roadside to Vehicle: ASK
Vehicle to Roadside: Subcarrier with PSK

Necessary Bandwidth:
Roadside to Vehicle: 1 MHz (500 kbaud)
Vehicle to Roadside: 500 kHz on subcarrier (250 kbaud)

Occupied Bandwidth: 2 channels, each 5 MHz
Roadside-to-Vehicle: Not Provided
Vehicle-to-Roadside: Not Provided

Antenna Parameters:
Roadside Unit: 12 dB gain
In-Vehicle Unit: 6 dB gain

Transmitted Power:
Roadside Unit: +33 dBm
In-Vehicle Unit: N/A, passive transponder

Receiver Sensitivity:

Roadside Unit: -110 dBm
In-Vehicle Unit: -45 dBm

Multi-Access technique: TDMA using the ALOHA protocol (probably slotted).

Message Transfer Capacity: 256 bytes per frame, probably Manchester encoded.
Roadside to Vehicle: 250 kbit/s (estimate)
Vehicle to Roadside: 125 kbit/s (estimate)

Permissible Operating Environment: All weather operation. Can be installed.for single or multi-lane environments.

Physical Deployment / Set-Up Constraints: Overhead installation of roadside reader antennas is the typical deployment. In-vehicle equipment consists of a transceiver with a "smartcard" slot.

Coverage Zone: Single lane or multi-lane configurations. Multi-lane configurations use multiple readers, each covering a single lane.

Cost of Infrastructure: Not provided.
Deployment:
NRE:

Cost of In-Vehicle Equipment: Depends heavily on functionality required.

Targeted Market: Electronic Toll Collection (ETC), Access Control, Electronic Toll and Traffic Management (ETTM)

Market Share: The first demonstration or test of the MobilPass system was near Stuttgart, Germany; and a second system was installed on the A555 Federal motorway as part of the German field trial for automatic motorway charging.

References:

'MobilPass: The Flexible System for Automatic Debiting and Access Control," System Description, Chapters I and II, March 27, 1995.

Email information received from Dr. Wolfgang Detlefsen of Bosch on January 25, 1996.

Name of System: **Hughes VRC (MACS - Advantage I-75)**

Manufacturer: Hughes Aircraft Company
Transportation Management Systems
Bldg. 675, MS DD311
1901 W. Malvern Avenue
Fullerton, CA 92634
Phone: (800) 494 - 5509
(714) 732 - 0848
Fax: (714) 732 - 1606

Contact Person: Dave Weingartner
Phone: (714) 446 - 2355
Fax: (714) 441 - 8246

System Description: The Hughes VRC (DSRC) is an open-road, multi-lane system using TDMA access, two-way packetized messaging and internal security to support a large number of IVHS applications. The Hughes VRC system is currently being used in the Advantage I-75 Mainline Automated Clearance System (MACS). The current implementation consists of a single-lane reader and in-vehicle transponder. The MACS is designed to allow trucks to bypass weigh stations. The Hughes VRC system is designed to identify the trucks, verify their credentials, and provide the truck drivers with indications as to whether or not they need to pull into a weigh station.

Detailed Specifications:

Operating Frequency: 902-915 MHz

Modulation Technique:
Roadside to Vehicle: Manchester encoded ASK.
Vehicle to Roadside: Manchester encoded ASK.

Necessary Bandwidth:
Roadside to Vehicle: Not Provided
Vehicle to Roadside: Not Provided

Occupied Bandwidth: (912-918 MHz Adv I-75)) (-55 dBm (c?))
Vehicle-to-Roadside: 6 MHz
Roadside-to-Vehicle: same

Antenna Parameters:
Roadside Unit: 12.04 dBi
In-Vehicle Unit: Compact antenna, probably very low gain.

Transmitted Power:

Roadside Unit: 30 dBm peak (Adv. I-75), 40 dBm EIRP incl. all losses
In-Vehicle Unit: 10 mW

Receiver Sensitivity:

Roadside Unit: Squelch: -46 dBm to -52 dBm, Sensitivity: -60 dBm
In-Vehicle Unit: -30 dBm (squelch) used in Advantage I-75

Multi-Access technique: Frame-oriented TDMA. Each frame is 10 msec long consists of a reader message, four message slots and 16 activation slots (similar to slotted ALOHA). The in-vehicle unit can transmit 512-bit packets that are typically addressed and acknowledged.

Message Transfer Capacity:

Roadside to Vehicle: 500 kbps
Vehicle to Roadside: 500 kbps

Permissible Operating Environment: All weather. Receiver squelch settings typically -30 dBm for the in-vehicle unit and -46 to -52 dBm for the roadside reader, thus reducing its vulnerability to interference. The roadside reader typically uses a directional antenna, further reducing its vulnerability to interference.

Physical Deployment / Set-Up Constraints: Overhead or roadside installation of the roadside antennas. The roadside antenna can be designed to cover 1 or more lanes of traffic. The in-vehicle equipment is typically mounted on the dashboard of the vehicle.

Coverage Zone: 100 to 200 feet free space range typical (Adv. I-75). Can be used in single lanes or multiple lanes.

Cost of Infrastructure:

Deployment: $10,000 for a standard Model 200 roadside reader capable of multiplexing 4 antennas. This reader is similar to that used in Advantage I-75; only one reader per antenna was used on Advantage I-75.
NRE:

Cost of In-Vehicle Equipment: Approximately $75 for a Type III, externally powered tag with serial output. $20 - $40 for a Type II (ETC) tag that is battery powered without an external interface.

Targeted Market: Electronic Toll and Traffic Management (ETTM), Advanced Traveler Information Systems (ATIS), Commercial Vehicle Operations (CVO)

Market Share: The installation of the MACS along I-75 is one of the largest operational field tests of DSRC equipment to date. MACS are currently being installed in the HELP Pre-Pass System; installations already include California and New Mexico. Currently performing a demonstration on the Ohio Turnpike. Various trucking companies use the system for access monitoring. Being used in a demonstration for Mexico border crossing. Currently being installed on Highway 407 in Canada for automated toll collection.

References:

Notes and specification received from Dave Weingartner, November 29, 1995.

Promotional literature, "Weigh Station Bypass System," Hughes Transportation Management Systems.

Parkany, A. E., and Bernstein, D., "Using VRC Data for Incident Detection," Pacific Rim TransTech Conference Proceedings, July 25 - 28, 1993, Vol. 1, pp. 63-68.

Deacon, J. A., Pigman, J. G., and Jacobs, T. H., "Implementing IVHS Technology: ADVANTAGE I-75 Approach," Proceedings of the Vehicular Navigation and Information System Conference 1991 (VNIS '91), Part 1, pp. 355-363.

Crabtree, J., "Advantage I-75 Prepares to Cut Ribbon on Electronic Clearance," Public Roads, Autumn 1995, pp. 16-21.

Telephone conversation with Dave Weingartner on January 18,1996.

Name of System: **Intellitag**

Manufacturer: Intellitag Products
A Motorola/Amtech Technology Partnership
17304 Preston Road, Bldg. E100
Dallas, Texas 75252

Contact Person: R. Rand Brown, Amtech Gary Butz, Amtech
Phone: (214) 733 - 6622 (214) 753 - 6441
Fax: (214) 733 - 6699

System Description: Intellitag products form a vehicle-to-roadside communications system capable of supporting ETC or ETTM applications. Intellitag is capable of providing "gateway" communications at high vehicle speeds when the vehicle passes within tens of meters of the reader. The system consists of IT2001 Reader (roadside), IT2410 tag programmer, and either the IT2101 tag mounted on inside of windshield or the IT2111 tag mounted to an exterior flat surface of the vehicle. The tags have 2564 bits of memory, which can be programmed using a wireless programmer (IT2410). The system is designed to meet or exceed all the CALTRANS specifications.

Detailed Specifications:

Operating Frequency: 902-928 MHz, programmable in 1 MHz steps.
In-vehicle tag frequency set by the roadside reader.

Modulation Technique:
Roadside to Vehicle: Manchester encoded ASK
Vehicle to Roadside: FSK Encoded (over the reflected signal from the reader)

Necessary Bandwidth:
Roadside to Vehicle: Not Provided
Vehicle to Roadside: Not Provided

Occupied Bandwidth:
Vehicle-to-Roadside: 6 MHz, -50 dBc
Roadside-to-Vehicle: 6 MHz, -50 dBc

Antenna Parameters:
Roadside Unit: Variable, Spec. sheets use 6 - 14 dBi as examples.
In-Vehicle Unit: Compact internal antennas, probably with low gain. Options include antennas designed for tag mounted directly on a metal surface and designed for installation at least one inch from a metal surface.

Transmitted Power:

Roadside Unit: 40 - 1000 mW, programmable in 1 dB increments

In-Vehicle Unit: N/A, uses backscatter technique

Receiver Sensitivity:

Roadside Unit: Not provided. See Coverage Zone for information on maximum operating ranges.

In-Vehicle Unit: Not provided.

Multi-Access technique: Uses a TDMA protocol called flex-frame TDMA. The user selects the activation and transaction slots in the frame. Fewer slots for sites requiring large data transfers in a short period of time and more slots to increase the number of simultaneous in-vehicle tags in the reader's field of view. Can be used for single lane coverage or multiple lane coverage.

Message Transfer Capacity:

Roadside to Vehicle: 600 kbps encoded, 300 kbps decoded

Vehicle to Roadside: 2400 kbps encoded, 600 kbps decoded.

Permissible Operating Environment:

Roadside Unit: Temperature: -40°C to +85°C
Humidity: 95% noncondensing
Vibration: 1g, 10 to 500 Hz RMS

In-Vehicle Unit: Temperature: -40°C to +85°C
Humidity: 100% condensing
Vibration: 2.0g, 5 to 2000 Hz RMS
Shock: 20g, 1/2 sine pulse, 6 ms duration, 3 axis

Physical Deployment / Set-Up Constraints: In-vehicle tags can be mounted inside the vehicle (typically hanging from the rear-view mirror) or mounted on the outside of the vehicle. The roadside reader is typically mounted above the roadway (or lane for single lane operation), or on the side of the road. Antenna gain and beamwidth determine the physical deployment necessary to achieve desired performance.

Coverage Zone: Either single lane coverage or multiple lane coverage with multiple access (TDMA) protocols. Operating range varies according to the gain of the antenna used with the reader (roadside unit). The typical maximum range is about 35 ft with 300 mW of reader output power measured at the input to the antenna.

Cost of Infrastructure:

Deployment: Standard reader unit $8,100 (single lane ETC), high power beacon reader $8,800, and reader with ATA $16,500 (essentially 2 readers in one).

NRE: Mean Time between repairs is 20,000 hours and typically the units are replaced rather than repaired. Also recommend that 10% reader spares are kept on hand at all times.

Cost of In-Vehicle Equipment: The following are list costs. Internal (dash) units list for $45.75 for the standard configuration and $50.75 with LED displays. External (license plate mount) units cost $55.50. Currently under development is a tag with an RS-232 serial interface for CVO applications, no cost available.

Targeted Market: Toll Collection, Traffic Monitoring, Vehicle-to-Roadside Communication (VRC), Commercial Vehicle Operations (CVO), and Advanced Traffic Management Systems (ATMS).

Market Share: Currently used by the Kansas Turnpike Authority, and older versions used on Oklahoma turnpike tolls. AmTech older tags also in use in GA 400 (Atlanta, Ga.), Crescent City Connection Bridge (Louisiana), Lake Pontchartrain Causeway (Louisiana), the New York Lincoln Tunnel, Oklahoma Turnpike, Texas Turnpike, the Sam Houston Tollway and Hardy Toll Road (Texas), and the Houston (Texas) Freeway Monitoring System.

References:

Sales and advertising brochures.

Majdi, S., "Houston ETTM Project: Use of AVI Technology for Freeway Traffic Management," Proceedings of the 1st World Congress on Applications of Transport Telematics & Intelligent Vehicle-Highway Systems, 1994, Vol. 2, pp. 712-718.

Tetsusaki, K., "High Security Electronic Toll and Traffic Management and Road Pricing System Using Encrypted Messages and Personal Identification Number," 1994 Vehicle Navigation & Information Systems Conference Proceedings, pp. 695-698.

Koelle, A. R., "Advances in Practical Implementation of AVI Systems," 1991 Vehicle Navigation & Information Systems Conference Proceedings, Part 2, pp. 969-975.

"Radio Frequency Identification (RFID)," Market Study, Air Force Automatic Identification Technology (AIT)) Program Management Office, May 1995.

Telephone conversation with Gary Butz on January 19, 1996.

Name of System: **GEC-Marconi : Traffic and Road Information Communications System (TRICS)**

Manufacturer:
Marconi Communications
GEC-Marconi Research Centre
West Hanningfield Road
Great Baddow, Chelmsford
Essex. CM2 8HN

Contact Person:
Richard (Dick) Baker
Marconi Communications, Inc.
11800 Sunrise Valley Drive, Tenth Floor
Reston Virginia 22091
Phone: (703) 620 - 0333
Fax: (703) 620 - 0415

Paul Kimber
GEC-Marconi
UK
011-44-1245-24-2856

System Description: TRICS was developed as part of the PROMETHEUS Short Range Communications Task Force (SRCTF). It is a 5.8 GHz, bi-directional vehicle-to-roadside communications (DSRC) system. The in-vehicle tags use a semi-passive technology that modulates a CW tone from the roadside reader by varying the reflectivity of the tag's antenna. The system is designed for use with smart cards. A variation of this system was used in the operational TELEPASS systems in Italy.

Detailed Specifications:

Operating Frequency: 5.8 GHz ± 5 MHz

Modulation Technique:
Roadside to Vehicle: ASK - On/Off Keying (OOK)
Vehicle to Roadside: Binary FSK (750 kHz and 1 MHz)

Necessary Bandwidth:
Roadside to Vehicle: 1 - 2 MHz (estimated)
Vehicle to Roadside: 2 MHz (estimated)

Occupied Bandwidth: Two channels - 5 Mhz each
Roadside-to-Vehicle: Not Provided
Vehicle-to-Roadside: Not Provided

Antenna Parameters:

Roadside Unit:	Transmit:	Horizontal BW ±40°
		Vertical BW ±6°
	Receive:	13 dB nominal gain
In-Vehicle Unit:	5 dB nominal gain, BW ±40° both axes	

Transmitted Power:

Roadside Unit: 33 dBm EIRP

In-Vehicle Unit: Subcarrier level approx. -10 dBm at 1 meter

Receiver Sensitivity:

Roadside Unit: < -95 dBm (5 dB Noise Figure)

In-Vehicle Unit: < -40 dBm at 250 kbit/sec downlink

Multi-Access technique: Narrow receive beam width of receiver provides separation of individual vehicles.

Message Transfer Capacity:

Roadside to Vehicle: 250 and/or 500 kbit/sec

Vehicle to Roadside: 125 kbit/sec

Permissible Operating Environment: Developed in Europe, this system would almost surely require site licensing for readers in the United States. It is designed to operate in all weather.

Physical Deployment / Set-Up Constraints: Typically uses overhead installation for monitoring of individual lanes. Road- or lane-side installation also possible.

Coverage Zone: Coverage range is 30 meters maximum, 15 meters typical. Designed for a small footprint coverage in a single lane.

Cost of Infrastructure: Not provided

Deployment:

NRE:

Cost of In-Vehicle Equipment: Not provided

Targeted Market: Electronic Toll Collection (ETC), Electronic Toll and Traffic Management (ETTM), Commercial Vehicle Operation (CVO), including fleet management

Market Share: Used in the European PROMETHEUS project, the operational TELEPASS system, and has undergone extensive multi-lane system testing in Italy, Singapore, and Germany. Though not specifically identified by name, this is probably the system tested in the Australian Microwave Toll Debiting Pilot Project.

References:

Notes and specifications sent by Paul K. Kimber, Chief Scientist, Transportation Avionics Laboratory, GEC-Marconi, November 17, 1995. Includes: Protocol for the Air Interface for the BMM '94, April 25, 1994 - Data Specifications for the TRICS Applications, July 11, 1993

Sales and advertising literature.

Bhandal, A., et al., "Short-Range Communications Systems Used by the Prometheus Project," Proceedings of the 1st World Conference on Applications of Transport Telematics & Intelligent Vehicle-Highway Systems, 1995, Vol. 5, pp. 2573-2580.

Name of System: **Mark IV - ROADCHECK**

Manufacturer: Mark IV IVHS, Inc.
212 Durham Avenue
Metuchen, New Jersey 08840
Phone: (908) 494 - 7720
Fax: (908) 484 - 8005

Contact Person: Paul Manuel (marketing) and Kelly Gravelle
Phone: (905) 624 - 3025
Fax: (905) 624 - 4572

System Description: The ROADCHECK systems provides two-way, short range communications between vehicles and host computer systems. Options include basic tags, which are simply read by the roadside reader; read/write vehicle tags with 512 bits of storage capacity; and read/write interfaces which allow the transfer of information to other in-vehicle systems (processors, ATIS, etc.). These are currently in use in field tests, and are due to become commercially available in the third quarter of 1996. They claim to have a dual protocol: one lane based, and one wide area.

Detailed Specifications:

Operating Frequency: 902 - 928 MHz, 915 MHz nominal, roadside reader requires licensing

Modulation Technique:
Roadside to Vehicle: AM, Manchester encoded
Vehicle to Roadside: AM, Manchester encoded

Necessary Bandwidth:
Roadside to Vehicle: Not Provided
Vehicle to Roadside: Not Provided

Occupied Bandwidth:
Roadside-to-Vehicle: Not Provided
Vehicle-to-Roadside: Not Provided

Antenna Parameters:
Roadside Unit: Multiple antenna choices including overhead flat panel antennas, in-pavement antennas and patch antennas (for fixed or mobile installations).
In-Vehicle Unit: Compact, probably etched printed circuit card, antennas with low gain and little or no directionality.

Transmitted Power: Specific to installation and application.
Roadside Unit:
In-Vehicle Unit: 1 mW

Receiver Sensitivity: Not published
Roadside Unit:
In-Vehicle Unit:

Multi-Access technique: Typically uses very short range communications in conjunction with time division access to cover multiple lanes. A single reader can cover eight lanes. It does have a wide area mode in which it interacts as a "wireless LAN." The access mode used in the Highway 407 project (Canada) is based on the combination of Slotted Aloha and Time Division Multiple Access (TDMA) protocols.

Message Transfer Capacity: 500 kbps ±10%

Permissible Operating Environment: The in-pavement antennas can operate through 6 inches of dry snow or 2 inches of debris (dirt, leaves, etc.).

Physical Deployment / Set-Up Constraints: Roadside antennas can be installed overhead for most applications. The system also includes the option of using in-pavement antennas.

Coverage Zone: The lane based (single-lane coverage for a single antenna) range is about 20 ft. Multiple lanes (up to 8) can be time multiplexed by a single reader. The open road operation (multiple-lane coverage for a single antenna) range is about 100 ft.

Cost of Infrastructure:

Deployment: These estimates assume that a single reader is multiplexed over 8 antennas:
$5,000 per lane for 1 antenna per lane (dual reader, 8 lanes per reader)
$10,000 per lane for dual antenna high reliability apps. such as ETC
$20,000 per lane for two-zone, Type III applications

Installation requires approximately 1/2 day field labor per lane per antenna.

NRE: After warrantee maintenance agreements cost around 15-20% of the original equipment costs.

Cost of In-Vehicle Equipment: The Type II (IAG) transponder cost is less than $25 (based on the IAG deposit amount). The Type III multi-mode (IAG and TDMA protocols) externally powered transponders cost approximately $75 - $100 in large volumes. Actual cost depends on options.

Targeted Market: Electronic Toll Collection (ETC), Commercial Vehicle Operations (CVO)

Market Share: The Mark IV technology has been in use for many years on the Heavy Electronic License Plate (HELP) project, currently known as Pre-Pass. It is being made compatible with the Advantage I-75/Highway 407 (AVION) project. In planning for use in the Atlantic City Parkway and Garden State Parkway (E-ZPass) in New Jersey.

References:

Sales and advertising literature sent by Paul Manuel on October 2, 1995.

Telephone conversation with Paul Manuel on January 18, 1996.

Name of System: **PREMID™: Trans Tag™ TS3100**

Manufacturer: Saab-Scania Combitech Traffic Systems
Box 1063, S-551 10 Jonhoping, Sweden
Phone: 46 36 19 43 00
Fax: 46 36 19 43 01

Also/

21300 Ridgetop Circle
Sterling, Virginia 20166
Phone: (703) 406 - 7284
Fax: (703) 406 - 7224

Contact Person: Ove Salomonsson, Vice President (Sterling, Virginia)

System Description: This is a semi-passive (backscatter) vehicle-to-roadside communications system. It operates at 2.45 GHz on both up- and down link with circular polarization. The communications link uses an active roadside reader and a reflective mode transponder in the vehicle. Size of transponder memory between 256 Bytes and 32 Kbytes. Wide product range available: portable reader/programmer broadcasting beacons, Type I and Type III tags (on-board electronics interface).

Detailed Specifications:

Operating Frequency: 2.45 GHz

Modulation Technique:
Roadside to Vehicle: Manchester encoded ASK
Vehicle to Roadside: FSK

Necessary Bandwidth:
Roadside to Vehicle: +/- 2.0 MHz
Vehicle to Roadside: +/- 2.0 MHz

Occupied Bandwidth:
Roadside-to-Vehicle: Not Provided
Vehicle-to-Roadside: Not Provided

Antenna Parameters:
Roadside Unit: 8-patch antenna, 14 dB gain
In-Vehicle Unit: low-gain compact antenna

Transmitted Power:
Roadside Unit: less than 500 mW EIRP (FCC Part 15 and Part 90 approval available
In-Vehicle Unit: reflective backscatter